REINFORCED CONCRETE CHIMNEY AT INDIANAPOLIS, IND.

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

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Reinforced concrete chimney
150' - 0' x 6 '- 6"

REINFORCED CONCRETE CHIMNEY

150' - 0" x 6' - 6"

PENNSYLVANIA LINES WEST OF PITTSBURGH

AT

INDIANAPOLIS, IND.

A THESIS PRESENTED BY

EDWIN G. WESTLUND

AND

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INTRODUCTION.

The chimney is as a rule the most conspicuous part of a power plant. It has important service to perform and its design and erection should receive intelligent thought and attention. Reinforced concrete is the ideal material for a chimney. Because of its elastic and monolithic nature a concrete chimney will withstand the attacks of the severest weather.

Draft

The inner diameter and height of the chimney are determined by the requirements of draft and capacity.

Draft produced by a chimney depends upon so many conditions and involves such a large number of variables that empirical methods of proportioning, based upon actual performances, are more to be relied upon than theoretical calculations. The intensity of draft required to produce best results depends upon the kind and condition of fuel, the thickness of the fire, character of the grate and resistance of the breeching tubes etc. The loss of draft in a chimney proper approximates 20% of the total; that in the

breeching is taken as 0.1 inch per 100 ft. of flue and 0.05 in. for each right-angled bend; the loss in the boiler varies from 0.3 to 0.6 in., depending upon the type. The loss of draft due to the different combustion rates of different fuels is taken from curves compiled by the Stirling Company.

The following is the data for this chimney:

Rated load 1350 H.P.
Max. overload 40% of rated.
Flue 140 ft. long
Two right-angle bends.
Average rate of combustion 20 lbs. of bituminous coal per sq. ft. of grate surface per hour.
Atmospheric temperature 60° F.
Flue gas temperature at overload 600° F.
Coal burned per boiler H.P. 5 lbs.
An additional allowance of 25% will be made for estimating the overload combustion rate.

$20 + (40 + 25)/100 \cdot 20 = 30$ lbs. per sq. ft. of grate surface per hour.

The draft required at the point where the flue enters the chimney considering the various losses will be as follows:

Furnace ("Stirling" curves)	0.20
Boiler	.40
Flue 140 ft. @ 0.1 in. per 100 ft.	.14
Turns 2 @ 0.05	.10
Total	0.84

Since the loss in the chimney approximates 20% of the total $0.84 \div 0.80 = 1.05$ inches will be the theoretical draft required.

Now, $D_1 = H\ (7.64/T_2 - 7.95/T_1)$ where

D_1 = intensity of draft in inches of water
H = height of stack
T_2 = absolute temperature of outside air
T_1 = absolute temperature of gases in chimney
$\therefore$ $1.05 = H\ (7.64/521 - 7.95/1061)$.

Solving for H, the height of stack shall be approximately 150 feet.
Substituting this value of H in Kents' formula, the effective area is found to be

$$E = 0.3\ H.P./\ H = .3 \times 1350/\ 150 = 33.1 \text{ sq. ft.}$$

corresponding to an actual diameter of 6 ft. 6 in.

GENERAL DESCRIPTION

The principle parts of the chimney are the foundation and the shaft.

The dimensions and proportions of parts must be chosen tentatively at first and then the chimney must be investigated as to its safety.

The foundation is octagon, 23 ft. wide, with open circular center, 8 ft. in diameter. Owing to the light weight of the whole structure, it is only necessary to go below the frost line or just deep enough to put below grade or 6 feet. The lower footing slab is 2 ft. thick and the foundation shall be sloped off in the next 2 ft. to an octagon 12 ft. 6 in. wide. The reinforcement consists of two networks of steel bars. The bars of the lower net run parallel to the sides and are about 24 in. apart. The bars of the

upper net are placed diagonally.

The thickness of the shell is 4 in. at the top, increasing 1/32 in. per ft. The shaft is tapered, the inside diameter increasing 5/16 in. per ft., the outside 3/8" per ft., making the outside diameter at the top 7 ft. 2 in. and at the base 11 ft. 11 in. An opening 9 ft. x 4 ft. is provided for flue connection 14 ft. 2 in. above grade, and also an opening. A radial brick lining is provided as described in another part of this thesis.

DESIGN

FOUNDATION

Estimate of Weight of Chimney. Thickness of shell increases 1/32" per foot. Outside diam. increases 3/8" per foot. The volume of the concrete in the shaft will be calculated by the Prismoidal formula, $V = 1/6\ (A_1 + A_m + A_2)$

where A_1 = area of the top section
A_m = area of the middle section
A_2 = area of the bottom section
and l = height considered.

Outside diam. of middle sect. = 7'-2" + 76 x 3/8" = 7'-2" + $28\frac{1}{2}$" = 9' - $6\frac{1}{2}$"

Thickness middle sect. = 4" + 76/32" = 4" + 2 3/8" = 6 3/8"

Inside diam. = 9' - $6\frac{1}{2}$" - $12\frac{3}{4}$" = 8' - $5\frac{3}{4}$"

Area of annular ring section = $\pi(r^2 - r_1^2)$

where r = outside radius and
r_1 = inside radius

$\therefore$ Area of top section $= \pi(r^2 - r_1^2)$

$= 3.14\ (\ 3.583^2 - 3.25^2\ ) = 7.23$ sq. ft.

Area of bottom section $= \pi\left[(5.958)^2 - (5.229)^2\right]$

$= 3.14\ (35.4 - 27.3) = 25.45$ sq. ft.

Area of middle section $= \pi\left[(4.77)^2 - (4.239)^2\right]$

$= 3.14\ (22.7 - 18) = 14.75$ sq. ft.

$\therefore$ Volume of stack $= 152/6\ (7.23 + 4 \times 14.75 + 25.45)$

$= 2320$ cu. ft.

Wt. of stack $= 2320 \times 150$ lbs. $= 348000$ lbs.

Area of octagon = Area of square of side L $\times$ 0.828, where L is the longest dimension of the octagon.

$\therefore$ Vol. of foundation $= .828\ (23 \times 23)^2 + 0.828\ (12.5 + 23/2)^2 \times 2 - \pi(4)^2 \times 4 = 873 + 522 - 200 = 1200$ cu. ft.

Wt. of foundation $= 1200 \times 150 =$ <u>180000</u> lbs.

Vol. of backfill $= 2\ (.828 \times 23 \times 23 - .828\ (11.92)^2) + 2\ (0.828 \times 23 \times 23 - 0.828 \times 17.5 \times 17.5) = 641 + 354 = 995$ cu. ft.

$\therefore$ Wt. of backfill $= 995 \times 110 = 109500$ lbs.

The average diam. of the brick wall lining = 11' - 11" - 2 x 12" = 9' - 11", say 10 ft.

Vol. $= \pi \times 10 \times 0.33 \times 50 = 523$ cu. ft.

Assume brick to weigh 125 lbs. per cu. ft.

$\therefore$ Wt. of lining $= 523 \times 125 = 65500$ lbs.

Total vertical load $= 65500 + 109500 + 180000 + 348000 =$ <u>703000</u> lbs.

WIND PRESSURE.

When wind blows against the curved surface of the chimney a part of it is ineffective, so that the effective pressure against the chimney is not more than two-thirds the normal pressure on a vertical plane whose width is the diameter of the chimney. The wind pressure will therefore be taken as 25 lbs. per sq. ft. of projected area, which corresponds to a wind of 100 miles per hour.

Projected area = $150/2\ (7.167 + 11.917)$ = 1430 sq. ft.

∴ Wind pressure = 1430 x 25 = 35800 lbs.

The resultant of the total vertical load and the wind pressure was obtained graphically in Plate I. The eccentricity of the resultant = 3.8 ft.

Vertical component = 70300 lbs.

Area of foundation = $0.828\ (23 \times 23)^2 - \pi(4)^2$ =

438.34 - 50.27 = 388.07 sq. ft.

∴ Pressure on earth at windward side

$V_1 = P/A\ (1 + 6 \times 3.8/388)$ = 1915 lbs. per sq. ft.

The soil is moderately dry clay, with a minimum safe bearing power of 4 tons. Therefore, the above value is well within the limits of safety.

Coefficient of friction = 0.5

Frictional resistance to sliding will be 0.5 x 703000

= 351500 lbs.

Wind pressure = 35800 lbs.

Therefore, it is safe with respect to sliding.

The portion AE acts as a cantilever to transmit the pressure to the soil and is reinforced on the lower side.

Total pressure on AE = 5.25 x 1915 = 10000 lbs.

Moment about E

M = 10000 x 2.625 = 26250 ft. lbs.

T = M ÷ jd, where d = 4' - 0" - 4" = 44 in.

j can be taken as 0.875

T = 12 x 26250/.875 x 44 = 8180 lbs. per lin. ft. of wall.

Area of steel req. = 8180/15000 = 0.545 sq. in. of wall.

Reinforcing consists of 40 - $\frac{3}{4}$" sq. twist. bars placed diagonally or practically 2 - $\frac{3}{4}$" sq. bars per linear ft. = 1.12 sq. in.

The shear = 10000 lbs.

Safe unit shearing strength is at least 25 lbs. per sq. in.

∴ Resistance to shear at section E = 12 x 48 x 25 = 14400 lbs.

Hence it is safe with respect to shear.

Bond, v = V/Eo·jd = 10000/6x.875x48 = 40 lbs. per sq. in.

SHAFT.

The aim is to design the shaft so that it will be as light as possible. The thinner the walls can be made, the less the danger there is of cracking under high and sudden temperature changes.

The thickness of the shaft must be sufficient to bear, with the steel imbedded in it, the pressure due to the weight of the chimney and to the wind. A proper number of vertical steel bars must therefore be inserted all around the chimney to resist the pull caused by the wind pressure.

Thicknesses of the shaft must be chosen tentatively at first and the stresses accurately computed. The thickness at the top is assumed as four (4) inches, increasing one (1) inch every thirty-two (32) feet making the thickness at the base eight and three-fourths ($8\frac{3}{4}$) inches.

VERTICAL REINFORCEMENT

A preliminary investigation will be made of the chimney at three different sections, i.e. grade, 50' - 0" above grade and 100' - 0" above grade. The area of steel required at these sections will be determined and a curve plotted (Plate 3) with height of chimney as ordinates and area of steel required as abscissa. By means of this curve, the amount of steel required at any section along chimney can be determined and the size and spacing of rods selected.

In this connection the following notation will be used throughout.

A = area of chimney sect. under consideration.
A_s = area of steel at section.
W = wt. of superincumbent portion of chimney
P = wind pressure on that portion
K = arm = H/3 x (2d + D)/(d + D) feet. Where H = ht. of chimney above sect. d = upper diam. D = lower diam.
M = overturning moment = P x K ft. lbs.
r = radius steel circle = inches.
e = distance from center of section to where the resultant of the weight and wind pressure cuts the section, "eccentric distance."
e/r = Eccentricity
f_c = unit stress in concrete adjacent to steel at the *lee side*
f_s = unit stress in steel at the windward side = $f_c$xc.
m = a coefficient such that f_c = W/A x m
p = steel ratio, i.e. A_s/A

The steel required is computed by the method suggested by Prof. E. R. Maurer, in"Principles of Reinforced Concrete Construction" and Engineering News, Sept. 10, 1908. The curves as deduced by him are shown in Plate 4.

GRADE.

W = wt. of shaft + lining = 34800 + 65500 = 413500 lbs.
A = 25.45 x 144 = 3670 sq. in.
W/A = 413500 ÷ 3670 = 95.
P = 35800 lbs.
K = 150/3 (2x7.17 + 11.85)/(7.17 + 11.85) = 68.7 ft.
M = 35800 x 68.7 = 2460000 ft. lbs.

From Plate I, e has been determined graphically = 5.95 ft. or 71.4 in.

r = 69 inches
e/r = 71.4 ÷ 69 = 1.04

It will first be assumed that the amount of steel is just sufficient to make f_c = 500. Then m = 500/95 = 5.27

Now, entering the diagram (Plate 4) at e/r = 1.04 and m = 5.27, we trace vertically and horizontally from these places respectively and note the intersection at p = 1/8% and f_s/f_c = 50.

∴ f_s = 50 x 500 = 25000# per sq. in. which is greatly in excess of the allowable stress (1600 lbs. per sq. in.) and necessitates the use of more steel.

Assume p = ½%

Then for e/r=1.04 and p = ½%, we note

m = 3.62 and f_s/f_c = 20
f_c = m W/A = 3.62 x 95 = 344 lbs. per sq. in.
f_s = 20 x 344 = 6900 lbs. per sq. in.

which is satisfactory.

For p = ½%, A_s = .005 x 3670 = 18.35 sq. in.

50 ft. above Grade.

Outside diam. = 7' - 2" ± 100 x 3/8" = 10' - 3½"

Thickness = 4" ± 100 x 1/32 = 7 1/8"

Inside diam. = 10' - 3½" - 14¼" = 9' - 1¼"

Area = $\pi(5.\overline{146}^2 - 4.\overline{552}^2)$ = 3.14 (26.4 - 20.7) = 17.9 sq. ft.

Outside diam. of middle section = 7' - 2" ± 50 x 3/8" = 8' - 8¾"

Thickness = 4" ± 50 x 1/32" = 4" ± 1 9/16" = 5 9/16 in.

Inside diam. = 8' - 8¾" - 11 1/8" = 7' - 9 5/8"

Area = $\pi(4.\overline{364}^2 - 3.\overline{902}^2)$ = 3.14 (19-15.2) = 11.95 sq. ft.

∴ Vol. above section = 1/6 (A_1 ± 4 A_m ± A_2) = 100/6 (7.23 ± 4 x 11.95 ± 17.9) = 1215 cu. ft.

∴ W = 1.215 x 150 = 182000 lbs.

W/A = 182000/17.9x144 = 71 lbs. per sq. in.

Projected area = 100/2 (7.167 + 10.292) = 873 sq. ft.

∴P = 873 x 25 = 21800 lbs.

K = 100/3 (2x7.167+10.292)(7.167+10.292) = 47 ft.

M = 21800 x 47 = 1025000 ft. lbs.

From Plate I, e = 5.6 ft. = 67.2 in.

r = 59.5 inches.
e/r = 67.2 ÷ 59.5 = 113

Then for f_c = 500, m = 500/71 = 7.04

Then for e/r = 1.13 and m = 7.04, Plate 4 gives

p < 1/8% and f_s/f_c > 50
f_s > 50x500 > 25000 lbs. per sq. in.

and thus necessitates the use of more steel.

Assume p = ¼%

Then for p = ¼% and e/r = 1.13, Pate 4 gives

m = 4.6 and f_s/f_c = 35
f_c = m x W/A = 4.6 x 7.1 = 327 lbs. per sq. in.
f_s = 35 x 327 = 11450 lbs. per sq. in.

which is satisfactory.

For p = ¼%, A_s = .0025 x 2580 = 6.65 sq. in.

Section 100' - 0" above Grade.

Area of top section = 7.23 sq. ft., above

Area of bottom section = 11.95 sq. ft., above

Outside diam. of middle section = 7' - 2" + 25 x 3/8"
= 7' - 11 3/8"

Thickness = 4" + 25 x 1/32" = 4 25/32"

Inside diam. = 7' - 11 3/8" - 9 9/16" = 7' - 1 13/16"

Area of middle section = $\pi(3.973^2 - 3.575^2)$ = 3.14 (15.75 - 12.8) = 9.28 sq. ft.

$\therefore$ Volume = $l/6\ (A_1 + 4\ A_m + A_2)$ = 50/6 (7.23 + 4x 9.28 + 11.95) = 469 cu. ft.

W = 469 x 150 = 70400 lbs.
A = 11.95 x 144 = 1720 sq. in.
W/A = 70400 ÷ 1720 = 41 lbs. per sq. in. due to W.

Projected area = 50/2 (7.167 + 8.729) = 398 sq. ft.

P = 398 x 25 = 9950 lbs.
K = 50/3 (2x7.167 + 8.729 // 7.167 + 8.729) = 24.2 ft.
M = 9950 x 24.2 = 241000 ft. lbs.

From Plate I, e = 3.39 ft. = 41 in.

r = 50 inches.
e/r = 41 ÷ 50 = 0.82

Then for f_c = 500, m = 500/41 = 20

These values of e/r and m fall beyond the limits of the diagram.

$\therefore$ Assume p = 0.20%

Then for p = 0.2% and e/r = 0.82

m = 3.0 and f_s/f_c = 13

$\therefore$ f_c = m W/A = 3 x 41 = 126 lbs. per sq. in.

f_s = 13x126 = 1640 lbs. per sq. in.

For p = 0.2%, A_s = .002x1720=3.45 sq. in.

The above values of steel area required at the three sections were plotted as in Plate 3. The size and number of bars were then selected as indicated in diagram and the stresses for such recalculated.

Section at Grade.

We will use 40 - 3/4"ø twisted bars at this section. $\therefore$ A_s = 40x0.5625 = 22.5 sq. in.
p = 22.5/3670 = .0061 or 0.61%

Then for p = 0.61% and e/r = 1.04, Plate 4 gives

m = 3.5 and f_s/f_c = 19

$\therefore$ f_c = m W/A = 3.5 x 95 = 332 lbs. per sq. in.

f_s = 19 x 332 = 6300 lbs. per sq. in. which is satisfactory.

Section 50' - 0" above Grade.

30 - $\frac{1}{2}$" sq. twisted bars will be used at this section.

$\therefore$ A_s = 30 x 0.25 = 7.5 sq. in.

p = 7.5/2580 = .0029 or 0.29%

Then for p = 0.29% and e/r = 1.13, Plate 4 gives

m = 4.5 and f_s/f_c = 33

$\therefore$ f_c = 4.5 x 71 = 320 lbs. per sq. in.

f_s = 33 x 320 = 10600 lbs. per sq. in.

Section 100' - 0" above Grade.

18 - $\frac{1}{2}$" sq. twisted bars will be used at this section.

$\therefore$ A_s = 18 x 0.25 = 4.5 sq. in.

p = 4.5/1720 = .0026 or 0.26%

Then for p = 0.26% and e/r = 0.82, Plate 4 gives

m = 2.95 and f_s/f_c = 13.

f_c = 2.95 x 41 = 121 lbs. per sq. in.

f_s = 13 x 121 = 1570 lbs. per sq. in.

Horizontal Reinforcement.

The vertical reinforcing bars in the shaft are encircled at regular intervals by horizontal rings. These rings take up all the stresses in the wall caused by high temperatures and also overcome the vertical shearing stresses caused by the wind pressure and resultant vibrations. The interior heat adds to the stress in the concrete and thereby increases the tendency to crack especially at points near the top of the inner lining. The horizontal rings are therefore spaced closer together at this point, as shown in plans. The interior heat affects the shell in another way because concrete is a poor conductor. The interior surface for a depth of an inch or two is heated very much hotter than the exterior surface and so tends to expand and crack the colder outside surface. The stress or pull on the outside surface must be met by the circular steel and by placing it near to this outside surface.

The steel is first chosen tentatively and the stresses investigated at three sections, the same as for the vertical steel. The rings will be spaced 12 inches center to center throughout, except for 8' - 0" at the top of lining, at which point they will be spaced 8 in. center to center owing to the higher and more sudden changes of temperature.

The following are formulas for the greatest unit compression in the concrete and the unit tension in the steel.

$$f_c = \tau K E_c m_c$$
$$f_s = \tau K E_s m_s$$

where, m_c and m_s are certain multipliers which depend on the percentage of hoop reinforcement, the position of the hoops relative to the outer and inner surfaces of the shell and the ratio of outer to inner radii. The multipliers are obtained from the curves, Plate 5, and f_c and f_s calculated. In this connection the following notation will be used

t = thickness of concrete shell at the section under consideration.

r_1 = inner radius of shell

r_2 = outer radius of shell

τ = difference of temperature of concrete at outer and inner faces.

K = coefficient of expansion of concrete and steel.

E_c = modulus of elasticity of concrete in compression.

E_s = modulus for steel.

f_c = temperature unit stress in concrete (circumferential) at inner face.

f_s = temperature unit stress in circumferential steel.

Section at Grade.

Outside diam. = 11' - $10\frac{1}{4}$"

Thickness = 8 11/16 in.

Steel - $\frac{1}{2}$" sq. bars, 12 in. center to center.

$\therefore$ $p = 0.25/(8.688 \times 12) = 0.0024$ or 0.24%

r_2 = 5 ft. 11 1/8 in. = 5.927

r_1 = 5 ft. 2 7/16 in. = 5.203

$r_2/r_1 = 5.927/5.203 = 1.14$

The bars are placed so that the center of the steel is 2 in. from the outer surface of the shell.

$\therefore$ K' = 2/8.688 = 0.23

Then, for K' = 0.3, p = 0.24% and r_2/r_1 = 1.1 the curves, Plate 5 gives

m_c = 0.176 and m_s = 0.465

Hence, if K = 0.000006, E_c = 2000000, E_s = 30000000 and the temperature difference at this point can be assumed to be a maximum of 150° Fahr.

$\therefore$ $f_c = \tau K E_c m_c$

= 150 x 0.000006 x 2000000 x 0.176

= 320 lbs. per sq. in.

and $f_s = \tau K E_c m_c$

= 150 x 0.000006 x 30000000 x 0.465

= 12600 lbs. per sq. in.

Section 50 ft. above Grade.

Outside diam. = 10 ft. $3\frac{1}{2}$ in. Thickness = 7 1/8 in.

Steel - $\frac{1}{2}$ in. sq. bars @ 8 in. centers.

$\therefore$ p = 0.25/(7.125 x 8) = .00438 = 0.438%

r_2 = 5 ft. 1 $\frac{3}{4}$ in. = 5.146

r_1 = 4 ft. 6 5/8 in. = 4.552

r_2/r_1 = 5.146/4.552 = 1.13

K' = 2/7.125 = 0.28

Then, for K' = 0.3, p = 0.44% and r_2/r_1 = 1.1 the curves, Plate 5, give

m_c = 0.225 and m_s = 0.42

At this point the difference in temperature will be the greatest owing to its proximity to the flue opening, with a maximum of possibly 200° Fahr.

$\therefore$ f_c = 200 x 0.000006 x 2000000 x 0.225

= 540 lbs. per sq. in.

and f_s = 200 x 0.000006 x 3000000 x 0.42

= 15100 lbs. per sq. in.

Section 100 ft. above Grade.

Outside diam. = 8 ft. $8\frac{3}{4}$ in. Thickness = 4 25/32 in.

Steel - $\frac{1}{2}$ in. sq. bars @ 12 in. centers.

$\therefore$ p = 0.25/4.781 x 12 = .0044 or 0.44%

r_2= 4 ft. 4 3/8" = 4.365

r_1= 3 ft. 11 19/32 in. = 3.966

r_2/r_1 = 4.365/3.966 = 1.1

K' = 2/4.781 = 0.42

Then, for K' = 0.4, p = 0.44% and r_2/r_1 = 1.1 the curves, Plate 5, give

m_c = 0.22 and m_s = 0.35

The temperature difference, τ, at this point will not exceed 150° Fahr.

$\therefore$ f_c = 150 x 0.000006 x 2000000 x 0.22

= 395 lbs. per sq. in.

and f_s = 150 x 0.000006 x 30000000 x 0.35

= 9450 lbs. per sq. in.

STRESS SHEET.

Item	Section at Grade	50 ft. above Grade	100 ft. above Grade.
W in lbs.	413500	182000	70400
A in sq. in.	3670	2580	1720
W/A in lbs./sq. in.	95	71	41
P in lbs.	35800	21800	9950
K in ft.	68.7	47	24.2
M in ft. lbs.	2460000	1025000	241000
e in in.	71.4	67.2	41
r in in.	69	59.5	50
e/r	1.04	1.13	0.82
Vertical Steel			
A_s in sq. in.	22.5	7.5	4.5
p in %	0.61	0.29	0.26
$f_c/W \div A$	3.5	4.5	2.95
f_s/f_c	19	33	13
f_c in lbs./sq. in.	332	320	121
f_s in lbs./sq. in.	6300	10600	1570
Horizontal Steel			
p in %	0.24	0.44	0.44
m_c	0.176	0.225	0.23
m_s	0.465	0.42	0.35
f_c in lbs. per sq. in.	320	540	395
f_s in lbs. per sq. in.	14600	15100	9450

LINING.

The object of the lining is to protect the exterior shell from the high heat of the boilers and also to provide an insulation which will prevent the lowering of the temperature of the gases which affect the draft.

Linings are designed, as yet, by precedent. It is common practice to place a firebrick lining in chimneys subjected to temperatures above 750° Fahr., and a common brick lining where 500° Fahr. is exceeded. The temperature in this case will average between 500° and 750° and accordingly a common brick lining will be employed.

Linings are generally carried one-third of the way up, so that if it is made 50 ft. high it will suffice. The thickness will be four (4) inches with an air space of two (2) inches between it and the outer shell. The lining must be entirely independent of the outer, as otherwise the expansion caused by the interior heat will tend to lift and crack the chimney at any points of contact.

ESTIMATE OF MATERIALS AND COST.

Materials.

Foundation. 1200 cu. ft. or 44.5 cu. yds.

For 1:3:6 concrete

Cement = 1.00 x 44.5 = 44.5 bbls.

Sand = 0.46 x 44.5 = 20.5 cu. yds.

Stone = 0.92 x 44.5 = 41.0 cu. yds.

Stack. Volume = 2320 cu. ft. or 86 cu. yds.

For 1:2½:4 concrete.

Cement = 1.35 x 86 = 116 bbls.

Sand = 0.52 x 86 = 44.7 cu. yds.

Stone = 0.82 x 86 = 70.5 cu. yds.

Lining. Volume of brick laid = 523 cu. ft. or 19.4 cu. yds.

A cu. yd. of masonry will require about 495 brick

∴ Number of brick = 19.4 x 495 = 9600

Allowance for breakage, etc. 3%=288

Total 9888

Say 1000 brick required.

A cu. yd. of the above masonry will require about 0.30 cu. yd. of mortar. ∴ Mortar req. = 0.3 x 19.4 = 5.82 cu. yd. For a 1:3 mixture of Portland Cement and sand, quantities of cement and sand required are as follows:

Sand = 0.95 x 5.82 = 5.5 cu. yd.

Cement = 2.36 x 5.82 = 13.7 bbls.

Total cement req. = 44.5 + 110 + 19.7 = 174.2 bbls.

Total sand req. = 20.5 + 44.7 +5.5 = 70.7 cu. yds.

Total Stone req. = 41 + 70.5 + = 111.5 cu. yds.

Steel.

Where lengthwise connections of vertical steel bars are made, the overlap shall not be less than 30 diameters or 30 x $\frac{3}{4}$ = 22.5 in. Say 2 feet.

Average length of horizontal rings = π d = 3.14 x 9.21 = 28.9 ft.

STEEL TABLE

Location	Size in.	Length ft.	Number	Wt. per ft.-lbs.	Weight lbs.
Foundation	$\frac{3}{4}$	9 - 0	32	1.913	552
Foundation	$\frac{3}{4}$	5 - 0	40	1.913	383
Shaft	$\frac{3}{4}$	22 - 0	40	1.913	1685
(Vert. Steel)	$\frac{3}{4}$	22 - 0	36	1.913	1515
" "	5/8	17 - 0	30	1.328	678
" "	$\frac{1}{2}$	22 - 0	30	0.85	562
" "	$\frac{1}{2}$	32 - 0	24	0.85	653
" "	$\frac{1}{2}$	56 - 0	18	0.85	857
(Horizontal Steel)	$\frac{1}{2}$	28.9	156	0.85	3830
			Total weight =		10714

LABOR.

The following Labor Table devised by Carl Weber is the result of years of practice in concrete chimney building. This chimney was built on the same general lines as were his and the table can therefore be utilized.

H is less than 25d, 150 < 25 x 6.5

∴ There will be 4 laborers.

There will be 2 carpenter days

10000/1500 = 7 days for bricklayers

and 14 days for helpers.

Total number of working days =

H/6 + 1 day for every 25 cu. yds. in foundation

= 150/6 + 44.5/25 = 27 days.

Excavation.

Vol. of excavation = (23 x 23 x 0.828) 6

= 2630 cu. ft. or 97.3 cu. yds.

Gillette, 17¢ per yd., picking, shoveling and hauling in wheelbarrows.

COST.

The cost of chimney construction depends upon the unit, cost of materials, the cost of labor per hour, the character of the labor and the probably weather conditions. The price of the materials, labor, etc., of course, varies with the market and locality. The following estimate is made using average prices and serves to illustrate the particular method for a chimney.

LABOR TABLE

Ins. diam.	No. of men Hand Work.	No. of men if Machine provided.	Remarks
3'0"	2	-	For Chimneys with H= over 25 x d take figures from next larger size.
4'0"	3	-	
4'6"	3	-	
5'0"	4	3	
5'6"	4	3	To find total No. of Working days = H/6 + 1 day for every 25 cu. yds. in foundation
6'0"	5	4	
6'6"	5	4	Make add. allowance for lining and if necessary for special work.
7'0"	5	4	
7'6"	6	5	
8'0"	6	5	
8'6"	7	5	Allow one Carpenter day for general lay and another for every opening in shaft.
9'0"	7	5	
9'6"	8	6	
10'0"	8	6	The number of men includes engine tender driver for horse and Foreman-assistant.
11'0"	9	6	
12'0"	10	6	
14'0"	12	6	The foreman however is not included.
18'0"	-	7	
20'0"	-	7	
25'0"	-	8	

ESTIMATE

Items of Expense	@	$ cts.
Materials:		
275 bbls. Portland Cement	1.50	412 50
71 cu. yds. Sand	1.25	88 75
112 cu. yds. Stone	1.50	168
10714 lbs. Steel	.02	214 50
10 M Bricks	12.33	123 30
Waterproofing		40
Labor:		
36 days Foreman	5.00	180
122 days Laborer	2.50	305
2 days Carpenter	3.50	7
7 days Bricklayers	6.00	42
Miscellaneous:		
Excavation 97.3 cu. yds.	0.17	14
Cleanout Door		15
Forms		50
Tools, Rope, Wire, etc.		20
Inspection		70
Office, Sales, Incidentals		150
	Total	1900 05

SPECIFICATIONS.

Dimensions:-

1. The principle dimensions of the chimney shall be as follows:-

Height of chimney above grade	150 ft. - in.
Depth of foundation below grade	6 ft.
Total height from base of foundation	156 ft.
Width of octagon foundation	23 ft.
Greatest thickness of octagon found	4 ft.
Inside diameter at top	6 ft. 8 in.
Thickness of wall at top	4 in.
Outside diameter at base of shaft	11 ft.11 in.
Thickness of wall at base of shaft	8¾ in.

Foundation:-

2. The concrete for the foundation shall be a mixture of one (1) part Portland cement, three (3) parts of sand and six (6) parts of crushed stone of not over two (2) inch size.

3. The steel reinforcement of the foundation shall consist of two (2) networks of twisted steel bars. The bars of the lower net shall run parallel to the sides, shall be laid four (4) inches from the base of foundation and shall be spaced twenty-four (24) inches center to center. The bars of the upper net shall be placed diagonally as shown in plans. The vertical bars of the shaft reinforcement shall be deflected and anchored under this steel grillage to form a secure anchorage.

Shaft:-

4. The concrete for the shaft shall be composed of one (1) part Portland cement two and one-half (2½) parts of sand and four (4) parts of crushed stone of not over 1-inch size.

5. The steel reinforcement of the shaft shall consist of vertical bars of square twisted steel and a series of horizontal sectional rings made of one-half (½) inch square twisted steel.

6. The size and spacing of the vertical bars shall be such that at a wind velocity of one hundred (100) miles per hour all the tensile stresses shall be taken up by these bars, and so that under this load the maximum tension on the steel shall not exceed sixteen thousand (16000) pounds per square inch of sectional area.

7. The horizontal reinforcement shall be spaced in accordance with the requirements due to wall thickness and temperature conditions. The bars shall be spaced twelve (12) inches center to center throughout except forty-eight (48) feet from the base of foundation at the top of lining, where they shall be spaced eight (8) inches for a distance of eight (8) feet.

8. Special reinforcement at the flue opening shall be provided, to consist of two (2) extra bars at each side of opening and two (2) extra rings on top and bottom of opening.

Lining:-

9. The brick for the lining shall be the best quality of whole new brick, burned hard entirely through, free from injurious cracks and with true even faces.

10. It must be thoroughly wet before being laid. Every brick shall be laid in full mortar joints, on bottom, sides, and ends, which for every brick is to be performed by one operation.

11. The lining shall be so constructed that the outside face will be two (2) inches from the inner face of the concrete stack.

12. The mortar shall be composed of one (1) part of cement and three (3) parts of dry sand, thoroughly mixed dry, and a sufficient quantity of water afterwards added to form a rather stiff paste. It shall be used within an hour after mixing, and not at all if once set.

Attachments:-

13. The chimney shall be provided with an opening for flue connection, nine (9) feet high and four (4) feet wide, fourteen (14) feet and two (2) inches above the grade line.

14. It shall also be provided with a standard cast-iron clean-out door of eighteen (18) by thirty (30) inch free opening, two (2) feet above the grade line.

Waterproofing:-

15. After removal of the last forms, the outer surfaces of the shaft shall be thoroughly cleaned and the entire sur-

face exposed to the influence of the atmosphere shall be treated with a waterproofing especially prepared for this work.

Materials:-

16. All materials used shall be of the b st and approved quality.

17. The cement shall be Portland, which will meet the requirements of the standard specifications adopted by the American Society for Testing Materials.

18. The sand shall be clean, sharp, coarse and of grains varying in size. It shall be free from sticks and other foreign matter, but it may contain clay or loam not to exceed five (5) per cent.

19. The stone shall be sound, hard and durable, crushed to sizes not exceeding one (1) inch in any direction for the shaft and two (2) inches for the foundation.

20. The water shall be clean and reasonably clear, free from sulphuric acid or strong alkalies.

21. The steel bars used for reinforcement shall conform to the "Manufacturer's Standard Specifications" for deformed bars and shall have an ultimate strength of not less than 64000 pounds per square inch.

Workmanship:-

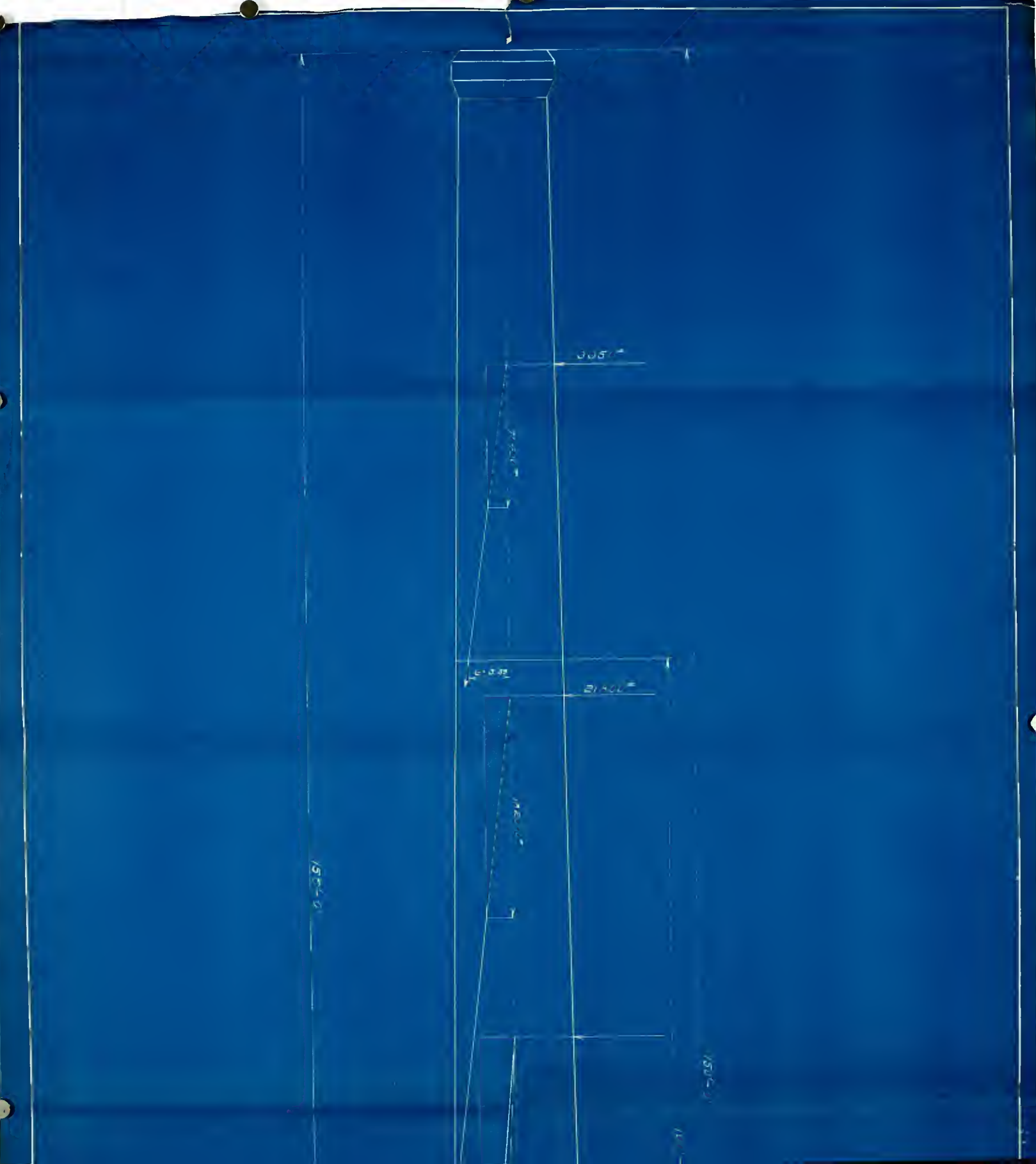
22. All work shall be done in first-class workmanship manner.

23. A tight platform shall be provided of sufficient size

to accommodate men and materials for mixing the concrete. The concrete shall be thoroughly mixed by at least three (3) turnings dry and three (3) turnings wet, so that every fragment is thoroughly coated with the cement mixture. The concrete shall be used immediately after preparation and shall be of such consistency that when dropped in place it will not require much tamping. It shall be spaded down and be tamped sufficiently to level it off, after which the water should rise freely to the surface.

24. Where fresh concrete is placed upon hardened surfaces, a cement grout made of one (1) part Portland cement and one (1) part of sand shall be used on the cleaned old surface to form the bonding joint.

25. All steel bars shall be properly spaced and placed as shown on working plans. Where lengthwise connections of steel bars are made, the overlap shall not be less than thirty (30) diameters.



THESIS

CHIMNEY 150' x 6'-6"

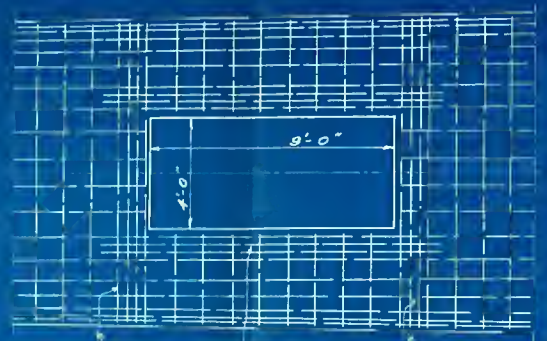
FOR

PENNSYLVANIA LINES WEST OF PITTSBURG

AT

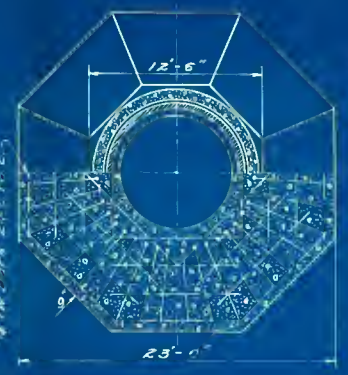
INDIANAPOLIS, IND.

PLATE 1. SCALE: INDICATED.



DETAIL OF FLUE OPENING
ARRANGEMENT OF STEEL
Scale 1/8"=1'-0"

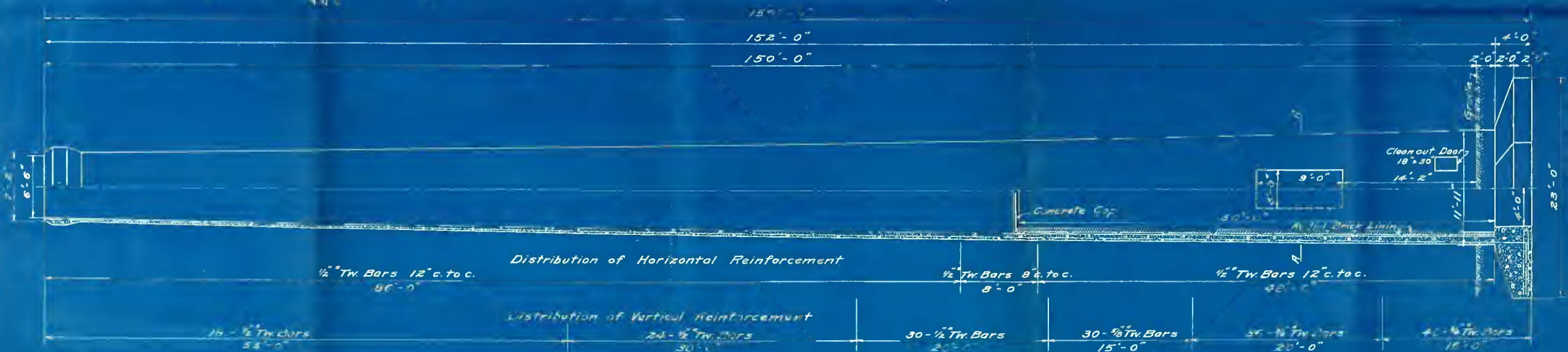
SECTION thru
Scale 1/8"=1'-0"



HALF PLAN and SECTION
OF FOUNDATION
Scale 1/4"=1'-0"

THESIS
CHIMNEY 137'-6" H.
FOR
PENNSYLVANIA LINES WEST OF PITTSBURG
AT
INDIANAPOLIS, IND.
PLATE 2 SCALE: AS INDICATED

159'-0"
152'-0"
150'-0"



Distribution of Horizontal Reinforcement

1/2" Tw. Bars 12" c. to c.
96'-0"

1/2" Tw. Bars 8" c. to c.
8'-0"

1/2" Tw. Bars 12" c. to c.
48'-0"

Distribution of Vertical Reinforcement

16 - 1/2" Tw. Bars
58'-0"

24 - 1/2" Tw. Bars
30'-0"

30 - 1/2" Tw. Bars
20'-0"

30 - 5/8" Tw. Bars
15'-0"

36 - 1/2" Tw. Bars
20'-0"

40 - 1/2" Tw. Bars
15'-0"

PLATE 3.

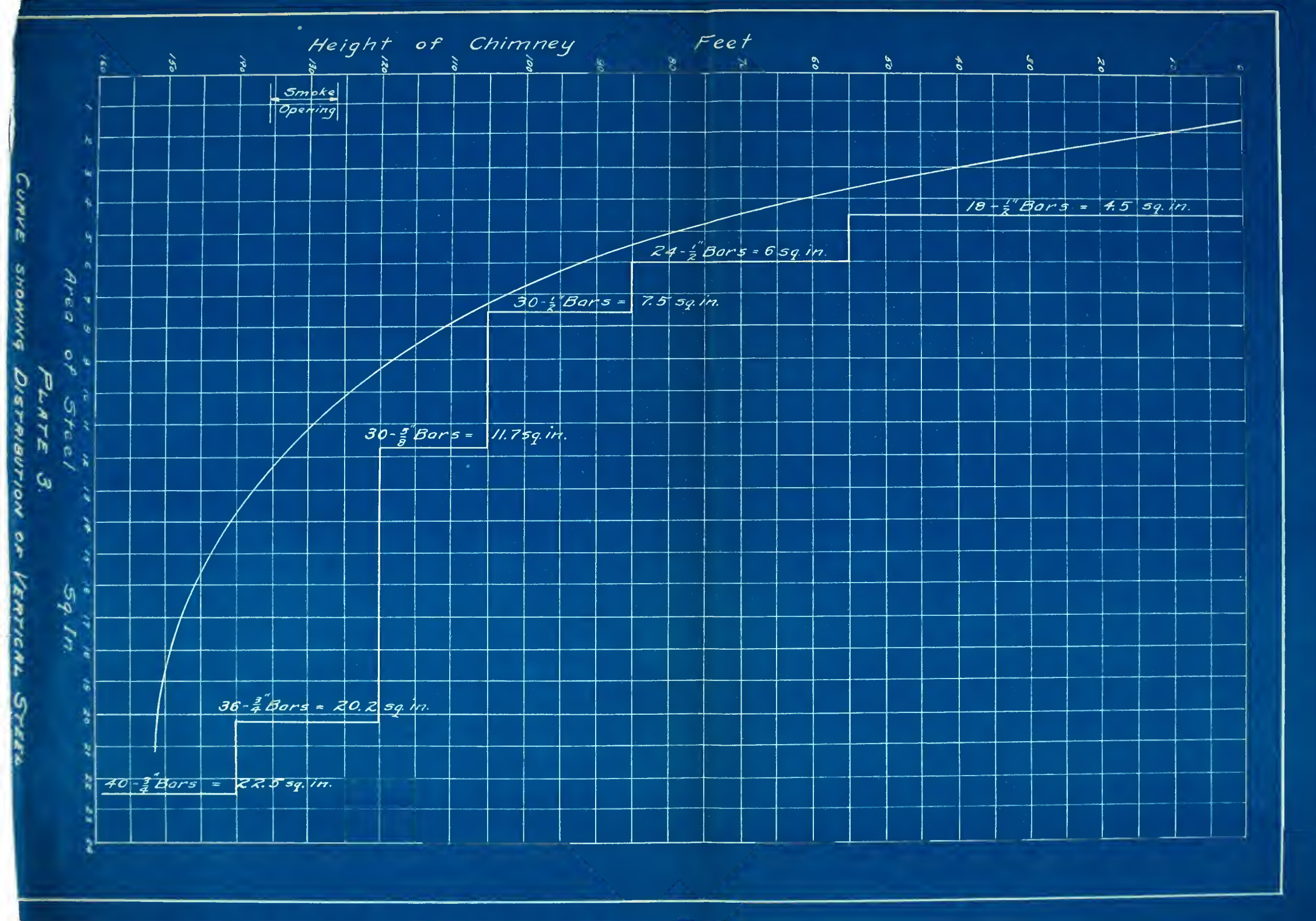

Height of Chimney Feet
Smoke Opening
18 - 1/2" Bars = 4.5 sq. in.
24 - 1/2" Bars = 6 sq. in.
30 - 1/2" Bars = 7.5 sq. in.
30 - 5/8" Bars = 11.75 sq. in.
36 - 3/4" Bars = 20.2 sq. in.
40 - 3/4" Bars = 22.5 sq. in.
Area of Steel Sq. In.

PLATE 3.

CURVE SHOWING DISTRIBUTION OF VERTICAL STEEL

WIND STRESSES IN REINFORCED CONCRETE CHIMNEYS

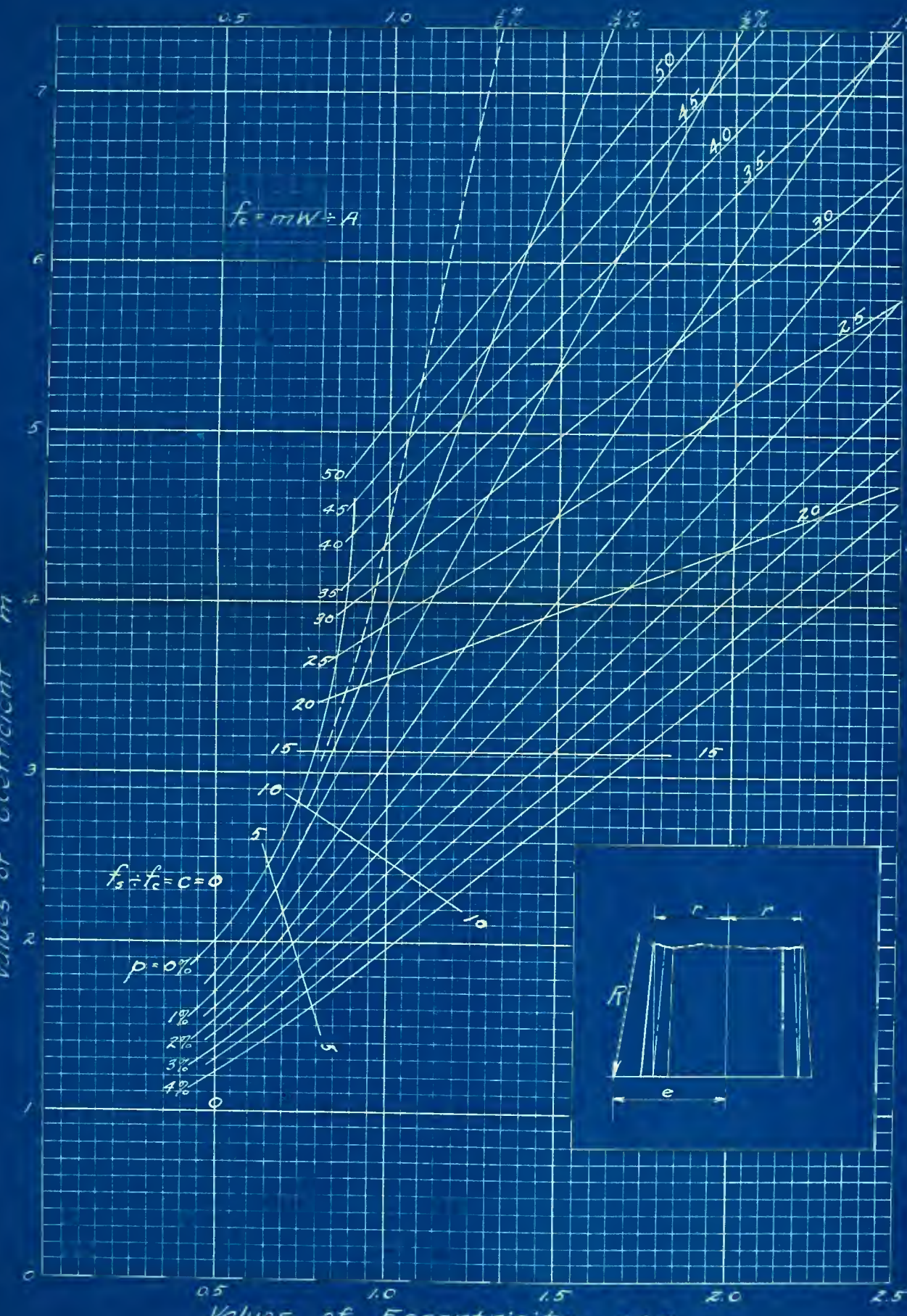


PLATE 4

CURVES FOR DETERMINING THE WIND STRESSES IN REINFORCED CONCRETE CHIMNEYS

Plate 5.

CURVES FOR DETERMINING THE

MULTIPLIERS USED IN FORMULA FOR TEMPERATURE STRESSES.

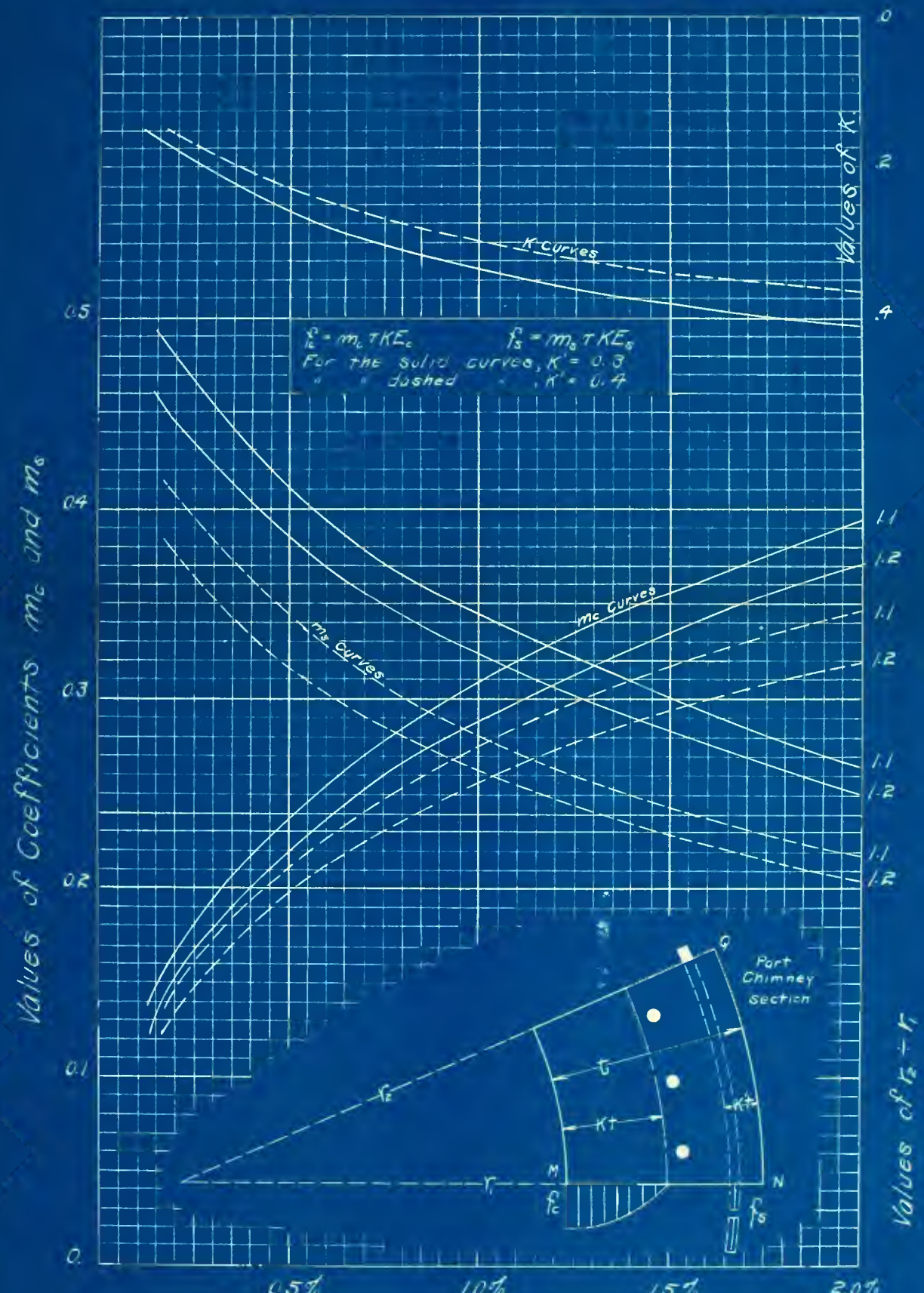


Plate 5.

CURVES FOR DETERMINING THE MULTIPLIERS USED IN FORMULA FOR TEMPERATURE STRESSES.

THESIS